High Electrode Loading Electric Vehicle Cell

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Project ID#
bat332

Timeline

- Project start: 15 June 2016
- Project end: 14 August 2019
- Percent complete: 90%

Budget

- Total project funding
- DOE share: $3,499,297
- 24M share: $3,499,297

- Funding received in FY18
  - DOE share: $1,581,536.62
  - 24M share: $2,453,077.54

- Funding for FY19
  - DOE share: $194,648.16
  - 24M share: $228,886.89

Barriers

- Cost – current costs are three times too high on a kWh basis
- Performance – High energy density battery systems are needed to meet both volume and weight targets
- Abuse tolerance, reliability, ruggedness – many Li-ion batteries are not intrinsically tolerant to abusive conditions

Partners

- 24M Technologies - LEAD

Company Facts

- 2010: company founded
  - Yet-Ming Chiang, Throop Wilder, W. Craig Carter
- 2014: automated line running
  - 32,000 sq.ft. facility
  - 50+ employees
- IP Portfolio: 50+(22) issued patents, 80+ pending
- Funding Events: $120M in equity
  - Three Financial Investors
  - Four Industrial Partners (GPSC/PTT, Kyocera, Itochu, etc.)
- DOE Grants:
  - $4.5M to date (Vehicle Technology, ARPA-E)
  - ARPA-E Grant: $1.2M thought 2019 (Lithium Metal)
  - USABC Awards: $7M through mid 2019 (EV)

Recognition

NEW ENERGY PIONEER 2016
Bloomberg NEW ENERGY FINANCE
WINNER

Global Cleantech 100
cleantech theguardian

2016 PLATTS GLOBAL ENERGY AWARDS FINALIST

Company Facts: Reinventing Lithium-Ion Manufacturing with SemiSolid Electrodes

DIFFERENTIATED TODAY: SEMISOLID TECHNOLOGY CREATES SUSTAINABLE COST ADVANTAGE IN $30B MARKET

- 25% lower cell cost via reduced bill of materials and simplified manufacturing process
- Half the capital cost per unit of manufacturing capacity installed ($/MWh)
- Innovative system designs leveraging large-format cells to reduce balance of system costs

COMMERCIALIZATION UNDERWAY: STRATEGIC PARTNERS BUILDING FACTORIES TO EXPLOIT TODAY'S TECHNOLOGY

- 100MWh/yr pilot factory in 2020, with potential to rapidly scale
- Major battery manufacturer signed on as EV development partner for high-energy density products
- Significant R&D funding via high-profile government programs

TRANSFORMATIVE TOMORROW: SEMISOLID PLATFORM ENABLES UNIQUE APPROACHES TO HIGH PERFORMANCE

- Achieve solid-state battery performance with significantly lower risk using dual electrolyte system
- Leverage differentiated silicon anode approach to high-energy density systems - move to 1st position
- Rapidly scale-up new technologies by integrating into existing 24M high volume manufacturing processes

- Overall Objective:
  - Develop and demonstrate EV-capable cells based on 24M's semi-solid electrode technology

- Objectives This Period:
  - Ship phase 2 deliverable cells to ANL
  - Increase the solids loading of active materials
  - Improve cycle and calendar life of high nickel content cathode active materials
  - Confirm superiority of semi-solid electrode abuse tolerance
  - Confirm feasibility of Si hybrid anode system

- Impact:
  - Demonstrate feasibility of low cost EV-capable cells based on 24M's semi-solid electrode

Milestones/Deliverables

Description of Milestone or Deliverable	Target Date	Status
Kick-Off	6/15/2016	Completed
Baseline Cell Gap Analysis Completed	12/14/2016	Completed
Gen1 Safety Design Review	1/25/2017	Completed
Cost Model Alignment	3/16/2017	Completed
Gen2 Cathode Active Material Down-selection	6/14/2017	Completed
Anode Active Material Down-selection (2-3 materials)	6/14/2017	Completed
Phase 1 Deliverables (GO/NO GO) (D1.1)	6/14/2017	Completed
Gen2 Electrolyte Lock (RT Life + HT stability)	8/4/2017	Completed
High vol% Loading Cathode	10/30/2017	Completed
Gen2 Alloy Anode Blend Formulation	11/29/2017	Completed
Next Gen Coating Process Proof-of-Principle	12/27/2017	Completed
Gen3 Electrolyte Lock	1/22/2018	Completed
Gen2 Safety Design Review	3/16/2018	Completed
Cathode Material Lock	6/14/2018	Completed
Anode Material Lock	6/14/2018	Completed
Active Materials Lock	6/14/2018	Completed
Phase 2 Deliverables (GO/NO GO) (D2.1)	6/14/2018	Completed
Next Gen Coating Process Down-Select	9/14/2018	Completed
Gen3 Cell Safety Design Review	12/14/2018	Completed
Final Electrolyte Lock	12/14/2018	Completed
Deliver >250cm^2 footprint Cells (D3.1)	12/14/2018	In progress, delayed
Phase 3 Deliverables (GO/NO GO) (D3.2)	4/14/2019	In progress, delayed
Cost Optimized Cell Designs	5/14/2019	In progress, delayed
Program Conclusion	6/14/2019	Future work

Phase 3 Status Dashboard

Task / Sub-Task	Status
1. High Energy Active Materials Selection	
1.1 Cathode Materials	
1.2 Anode Materials	
2. Increase Solids Loading	
3. Cell Architecture Development	
3.1 High-Energy-Active Electrode Forming	
3.2 Safety and Abuse Interventions	
3.3 Electrolyte Development	
4. Cost Modeling	
5. Cell Deliverables	
5.1 Benchmarking Cells	
5.2 Phase 3 Deliverables	

Key	
On Schedule	
Behind Schedule (<1Q); Corrective Action ID'd	
Off-Schedule (>1Q); No Corrective Action ID'd	

Approach/Strategy : Semi-Solid Technology Enable Thick Electrode & Simplified Process

Simplified Process

24M has better capital efficiency (lower upfront CapEx) and lower operating costs because we use less equipment, labor, energy, space, and time

CONVENTIONAL 13 Steps

Electrode Creation | *Cell Assembly*

Solvent Recovery

Anode	Mix	Coat	Dry	Inspect	Slit	Calendar	Die Punch	Clean	Vacuum Dry	Stack	Weld	Insert	Electrolyte
Cathode	Mix	Coat	Dry	Inspect	Slit	Calendar	Die Punch	Clean	Vacuum Dry				

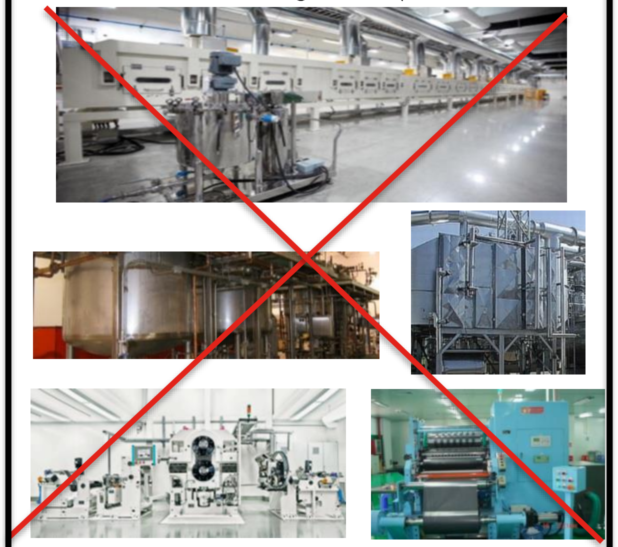
Solvent Recovery

24M 5 Steps

Electrode Creation | *Cell Assembly*

Anode	Mix	Coat	Stack	Weld	Insert
Cathode	Mix	Coat			

Do not require heavy equipment (Large Coater, Mixer, NMP Recovery, Slitting, Press)

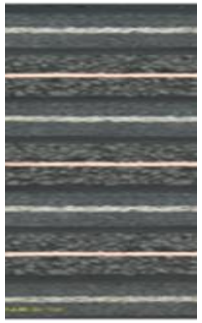


Thick Electrodes

24M has a structural Bill of Materials cost advantage because thick electrodes require less inactive material (copper, aluminum, separator and no binder)

CONVENTIONAL | **24M**

1mm Cross Section of Cells



2-3mAh/cm² VS 7-13mAh/cm²

60-110 microns VS 300-500 microns

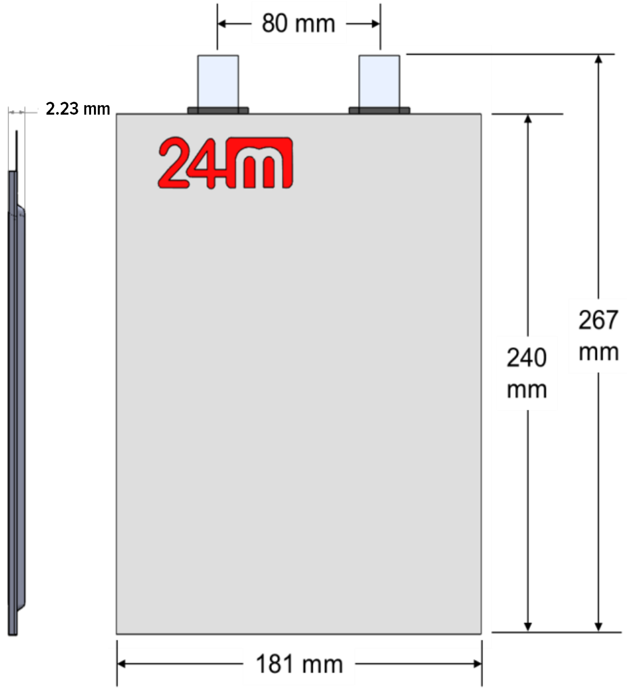
Components		24M BOM Advantage Conventional	24M
Cathode	LFP	100%	----
	Carbon	100%	----
	Binder	100%	-100%
	Electrolyte	100%	-4%
	Al. Foil	100%	-61%
	NMP	100%	-100%
Anode	Graphite	100%	----
	Carbon	100%	----
	Binder	100%	-100%
	Electrolyte	100%	-12%
	Copper foil	100%	-63%
Package	Separator	100%	-82%
	Pouch	100%	-10%
	Tab/Tape	100%	-10%
TOTAL:		100%	-25 to 40%

25 to 40% BOM Cost Reduction.

Technical Accomplishment to Date – FY18

- Shipped Phase 2 deliverable cells to ANL for independent testing,
- Achieved more than 500 cycles with NMC811 semi-solid cathode at C/3 discharge rate,
- Less than 5% capacity degradation after more than 400 DST cycles,
- Achieved EUCAR 2 in overcharge with NMC811 semi-solid cathode (12Ah pouch cell),
- Enabled high solid content slurries manufacturing with improved casting equipment,
- Identified root cause of resistance increase of NMC811 semi-solid cathode,
- Confirmed feasibility of Si hybrid anode concept

Shipped Phase 2 Deliverable Cells to ANL: NMC811/Graphite

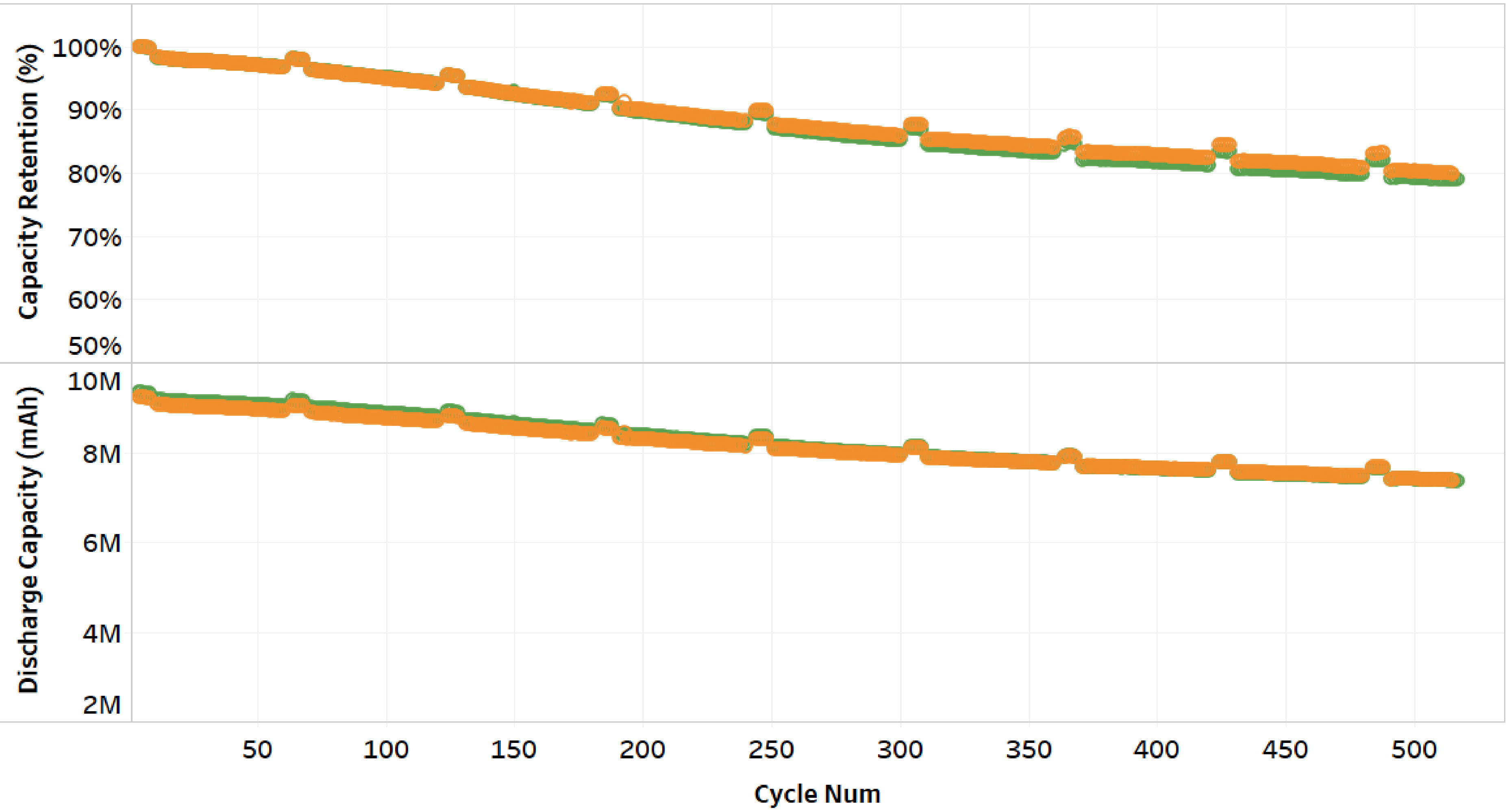


CELL INITIAL PERFORMANCE	
Nominal Capacity, C/3, 25ºC	11.48 Ah
Peak Discharge Power Density, 30 s Pulse	2152 / 1878 W/L
Peak Specific Discharge Power , 30 s Pulse	1025 / 963.5 W/kg
Peak Specific Regen Power , 10 s Pulse	561 / 527 W/kg
Energy Density @ C/3 Discharge Rate	545 / 476 Wh/L*
Specific Energy @ C/3 Discharge Rate	273 / 256 Wh/kg*
Areal Capacity	9.3 mA/cm^2
Nominal Roundtrip Energy Efficiency, C/3 rate	92%
Maximum Operating Voltage, Continuous/Pulse (V)	4.2/4.3
Minimum Operating Voltage, Continuous/Pulse (V)	2.7/2.5
Maximum Self-discharge	<1.5%/month

* (Jellyroll/ designed cell density),
Weight : 94%, Volume: 87.3% efficiency from Jellyroll

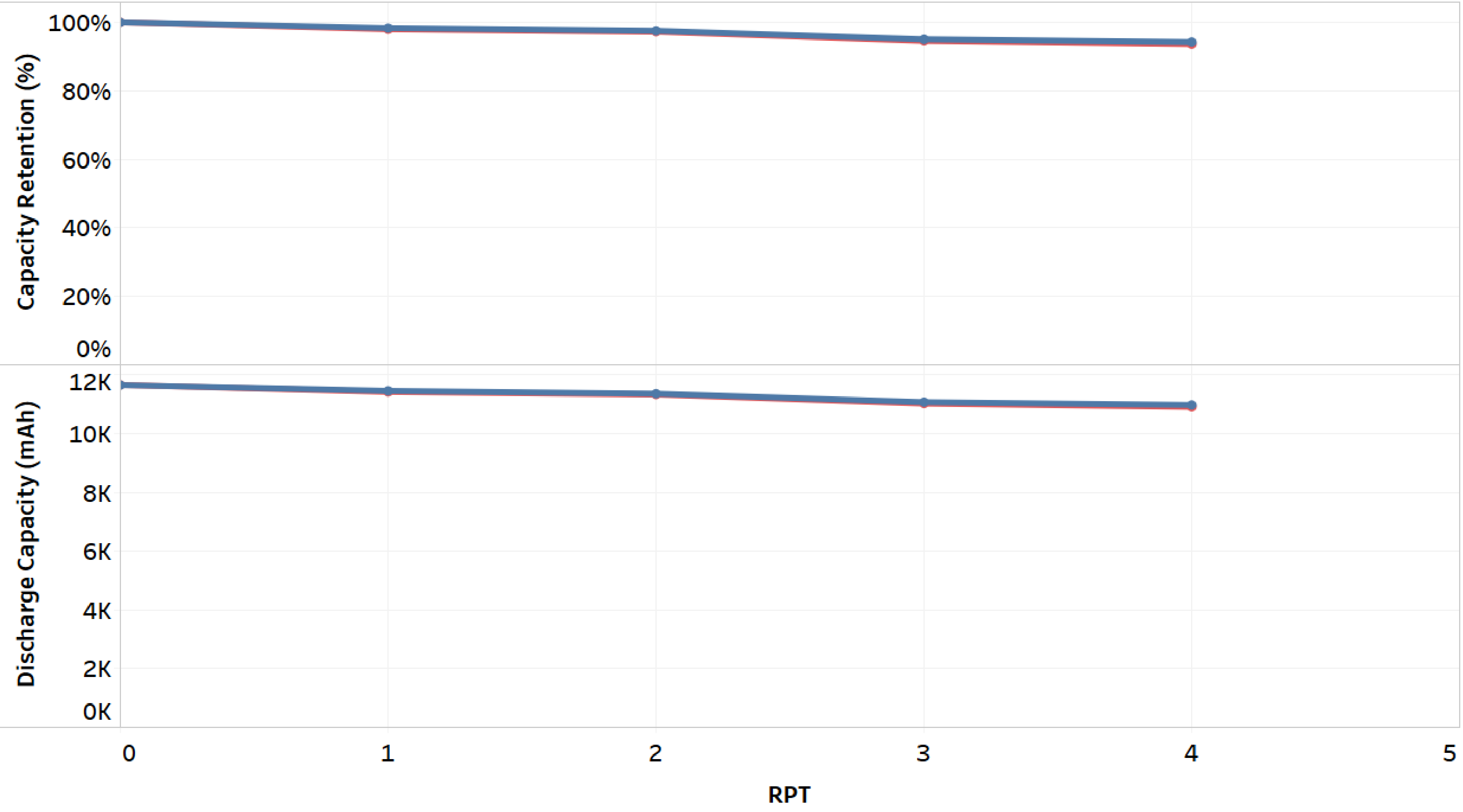
Achieved more than 500 cycles with NMC811 semisolid cathode

- Duty cycle : C/4 Charge to 4.2V, C/3 Discharge to 2.8V, 30^{0}C Cycling temperature. C/10 RPT capacity check every 50 cycles
- All cells started testing without prior aging

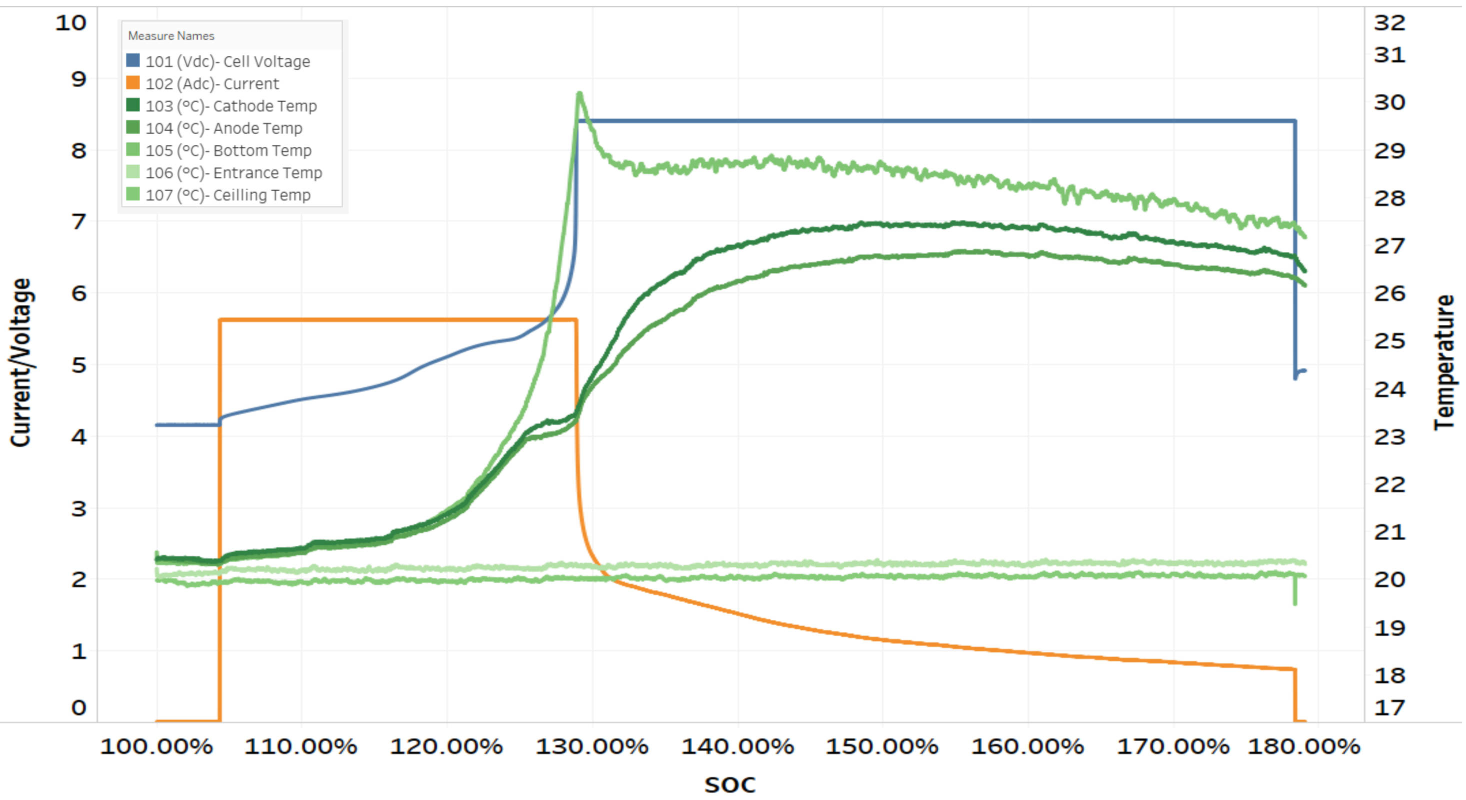


Achieved more than 400 DST cycles with NMC811 semisolid cathode

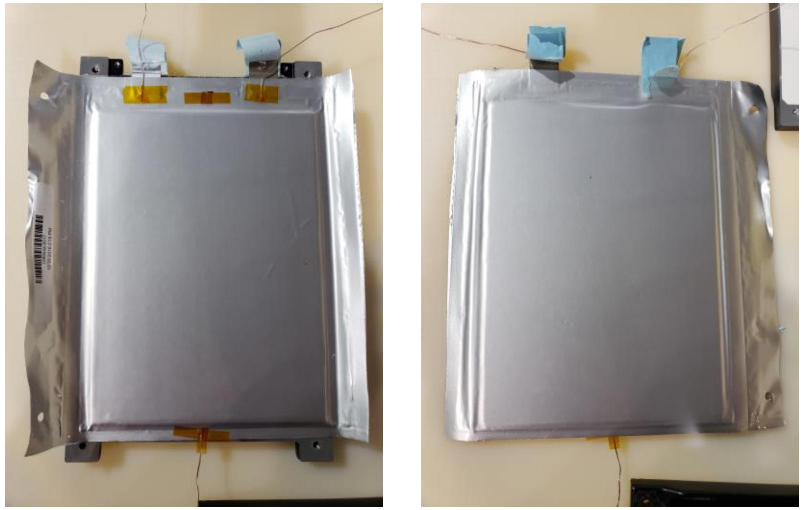
- RPT completed every 31 days. 103 cycles completed every 31 days,
- All cells started testing without prior aging



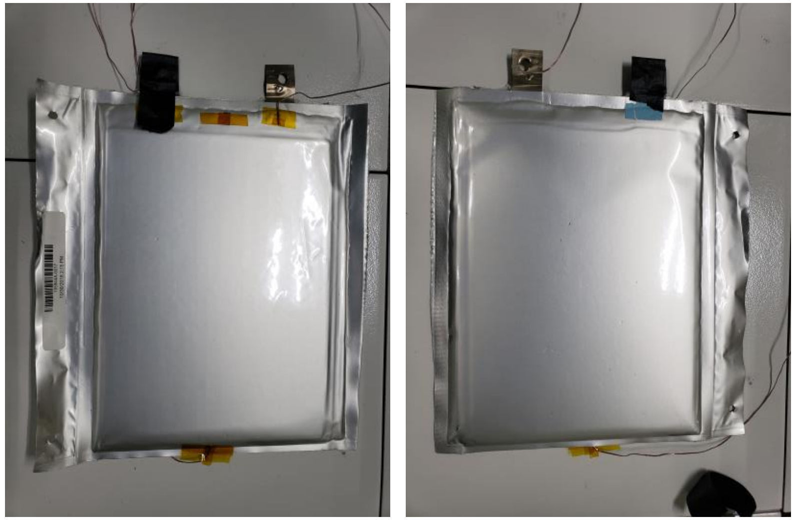
Achieved EUCAR 2 in overcharge with NMC811 semisolid cathode



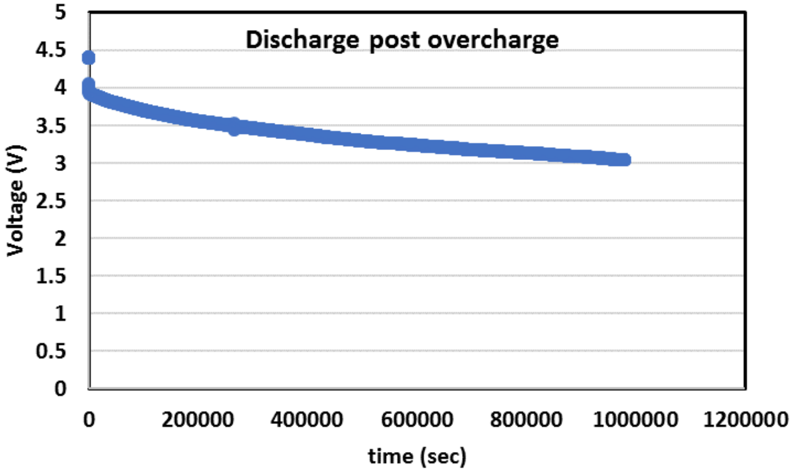
Before Overcharge



After Overcharge

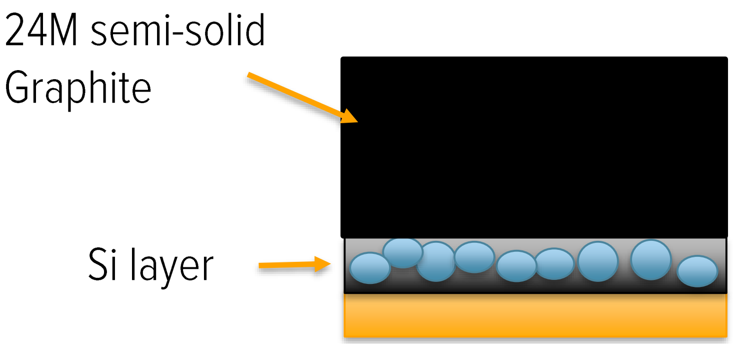


Two cells - Data	
Max Voltage	8.4V
Max Temperature	30.2°C
Time to max voltage	44min
OCV After Test	4.91V
EUCAR level	2



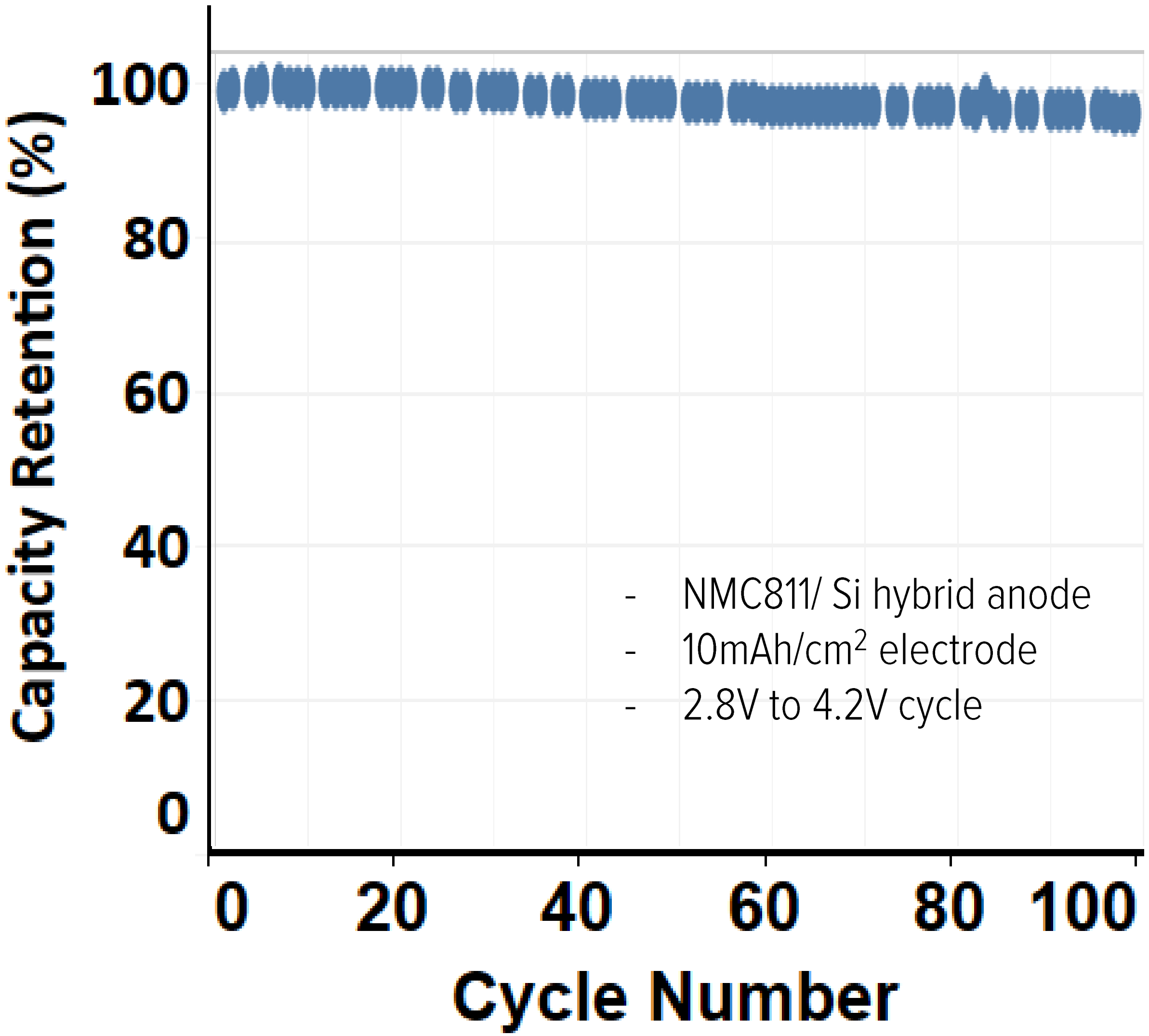
Confirmed feasibility of Si Hybrid Anode Concept

Si Hybrid Anode System



Thin traditional or Spattered electrode plus thick 24M semi-solid electrode combination

- Utilize 24M's thick electrode capability,
- Utilize thin silicon electrode cycle durability,
- Best use of potential differences of Si and Graphite and overpotential of thick electrode.



Partnerships / Collaborations

Argonne NATIONAL LABORATORY	Conduct electrical testing to verify the performance and life capability of deliverable cells vs. target performance
Sandia National Laboratories *Exceptional service in the national interest*	Conduct abuse testing to verify the performance of deliverable cells vs. target performance

Remaining Challenges and Barriers

- Meeting Phase 3 EOL available energy requirements (350 Wh/kg & 750 Wh/L),
- Meeting Phase 3 EOL 3.2C fast charge requirement (80% in 15min),
- Meeting Phase 3 EOL Useable Energy @ -20^{0}C requirement (> 70%),
- Fast Resistance increase of High Energy Cathode

Proposed Future Work

- Continue phase 3 development,
- Deliver Phase 3 deliverable cells for testing at Argonne National Lab by August 6, 2019
- Execute on high energy density initiatives to achieve Phase 3 targets,
- Execute on life improvement initiatives to achieve Phase 3 targets

"Any proposed future work is subject to change based on funding levels"

Summary

- Delivered phase 2 cells – further confirmation of the versatility of the semisolid electrode platform,
- Achieved more than 500 cycles with semi-solid NMC811 cathode,
- Demonstrated exceptional overcharge behavior of semi-solid NMC811 cells,
- Confirmed feasibility of Si Hybrid anode system,
- High energy cells exhibit high resistance increase
  - Identified corrective actions that will be implemented before phase 3 deliverable cells build,
- Planning to deliver 40Ah pouch cells for phase 3

24m